A Simulation System for Study of Traffic Flow Behavior

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During the past decade a rapid increase in the development of computing technology has increased interest in the use of digital computers as a means of simulating traffic flow. The development of simulation concepts has advanced from simple deterministic models which considered only a few elements of the driver, vehicle, and environment to stochastic models which introduce complex interaction between the vehicle-driver and the physical environment.

One of the major problems in introducing simulation techniques as a tool for the study of design and operational problems on highway systems is the difficulty encountered in programming simulation problems which can be learned with the expenditure of a limited amount of time. The authors report the development of a simulation system that utilizes a language called SIMCAR which has a generalized capability for programming traffic simulation problems. The source language closely resembles the language used by design and traffic engineers. Using the SIMCAR language, the geometry of a highway, the characteristics of vehicles and drivers and the control elements may be completely specified with only a limited amount of specialized training in computer programming.

Work being carried out by the authors to validate the model is not yet complete. However, models programmed with the SIMCAR language have been run for extended periods of time and have produced data which pass the test of reasonableness. At present an extensive program of model validation is being carried out.

•THE SIMULATION of traffic flow as a means of studying traffic behavior is not a new concept. Almost a decade ago Goode (1) considered the problems involved in producing useful traffic simulations. At an even earlier date pioneering work was being carried out by Gerlough, Trautman, Mathewson, and others (2, 3). One factor that has given tremendous impetus to advances in traffic simulation is the increase in capability of general purpose digital computers during the past decade. Capacity, speed, and logic have continued to improve rapidly. What was only theoretically possible five years ago can be achieved with ease today as a result of improved hardware capability.

DEVELOPMENT OF TRAFFIC FLOW SIMULATION CONCEPTS

There are many reasons why a traffic flow simulator with generalized capabilities is a desirable tool for those concerned with highway operations:

1. It can provide a means of studying the effect of different types of highway design on traffic flow behavior. At present, there is no way of determining how a new design

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will affect traffic flow short of actually building the installation and observing what happens to traffic as it moves over it.

2. It offers the ability to determine in advance the effect of increased traffic volume on existing facilities. Probable congestion points and accident locations could be anticipated and changes in the physical design of the highway could be effected ahead of time.

3. It would provide a means for studying the effect of control measures on existing highways. The effect of traffic signals, limitations on speed, stop signs, and suppression of marginal development could all be studied in detail.

4. It would offer a means of studying accidents and near-accidents to identify factors related both to the driver, the vehicle, and their interaction with the physical environment leading to a better understanding of how accidents occur. Such study is impossible in real life since the observers are generally the drivers involved, who rarely are in a position to report objectively the maneuvers just prior to the accident, and even if they were, would be faced with tremendous difficulties in bringing this information to some central point.

A considerable amount of work has already been carried out in the field of traffic flow simulation. The first papers to discuss the application of modern digital computers to the problem of traffic flow simulation began to appear as early as 1952. Since that time, various groups have constructed simulation models which have produced plausible results when compared with real data. One of the most complex simulation models for traffic flow that has been developed to date is that constructed by Stark (4) at the U. S. Bureau of Standards to simulate the flow of traffic on a 4-lane, one-way street in an urban area.

The evolution of digital computer simulation in the traffic field has been characterized by progress from simple, rigidly deterministic models to increasingly complex stochastic models. In the early models, only a limited number of factors were considered; usually speed of vehicle, impediments in the roadway such as other vehicles, and control devices. Vehicles were moved within the computer according to known physical laws, i.e., speed, acceleration, and stopping distances. Driver and vehicle behavior were treated in an idealized fashion with all vehicles exhibiting perfect behavior. Collisions as such were virtually impossible with traffic behaving as it might if all drivers had perfect perception of and reaction to events that affect them. However, even these simple models have demonstrated their utility by producing realistic information concerning such matters as the effect of signal timing on delays at intersections and the gap acceptance behavior of vehicles entering freeway traffic.

Progress in traffic flow simulation has been in the direction of including more environmental factors and driver characteristics in the model and utilizing stochastic rather than deterministic models. Stochastic models have helped minimize one of the more serious defects of deterministic models by producing driver behavior that is less than perfect. Mistakes in driving can and do occur and accidents as well as other malfunctions occur within the system.

Most traffic flow simulation models that have been programmed for digital computers in the past have been limited to specific rather than general problems. Typical programs have dealt with traffic flow on one-way streets (5), freeway operations (6) and on-ramp simulations (7).

Nevertheless, these models have made significant contributions to the development of the conceptual approaches required for more generalized simulators. The models developed, programmed, and reported in the literature must, for the most part, be considered experimental efforts designed primarily to explore the feasibility of implementing traffic simulation on digital computers. None of the models presented so far have been seriously considered as working tools for the engineer or traffic researcher in the study of traffic behavior. The exception to this may be the newly reported TRANS system developed at Thompson Ramo Woolridge (8).

REQUIREMENTS FOR DIGITAL SIMULATION

There are several problems involved in simulating traffic flow yet to be resolved before simulation can become a useful tool. First, and perhaps most obvious, is the question of whether useful simulation of traffic flow can actually be performed. Simulation to be useful, must satisfy three considerations:

1. The results of the simulation must fit the facts; in other words, observations obtained as a result of simulation must agree with similar results obtained from observations of actual traffic flow.
2. The time required to simulate a problem must be reasonable; that is, the ratio of simulated time to real time must be such that computer simulation of highway networks is economically feasible.
3. The results of simulation must be accessible in a form that is meaningful to those using them. The actual simulation takes place within the computer and is, of course, unobservable to the user; thus it is necessary to devise some means of displaying simulation results in a form convenient for the user.

A review of work undertaken by others and the result of our initial work suggests that simulation, particularly stochastic simulation, is a practical and feasible means of studying traffic flow behavior. A comparison of results generated by several different simulation models with data obtained from observations of actual traffic flow behavior has shown a correspondence sufficiently close to at least satisfy the criterion of reasonableness. The ratio of real to simulated time has varied with different models reported in literature, but most seem to place simulation in the economically feasible category. For example, the simulation system reported in this paper will simulate a complex 3-mile highway segment with moderately heavy traffic volume at a rate of 1 hour of running time equal to 6 hours of real time.

The problem of providing output in a usable form continues to be a difficult one. Many approaches have been tried, including the use of cathode ray tubes for direct display. We have approached the problem by providing a wide range of reports selectively available at the option of the user. It appears that the problem of output display, while difficult, is not insurmountable and that both direct display and selective digital output can produce satisfactory results.

Thus, it appears that in principle, traffic flow simulation is feasible on any large-size general-purpose digital computer, from both a technological and economic standpoint. It was from this set of assumptions that the present system was conceived. It was assumed that there was no question of the feasibility of simulation, and that the problem was one of developing simulation to the level of a tool for studying traffic flow problems.

The most serious obstacle to removing traffic flow simulation from the category of an experimental technique is the lack of a suitable programming language. The development of a simulation model to the point where it can be run on a digital computer involves several steps. The problem to be simulated must be defined by means of some symbolic notation and converted to a rough flow chart showing the general relationships involved. Subsequently the problem is reduced to a detailed flow diagram and coded into a set of instructions that comprise the computer program. The work involved in preparing and coding even a simple traffic flow problem that has limited application may require several months of work by someone skilled in computer programming.

All too frequently the potential user of simulation techniques is not a skilled programmer. This necessitates either taking the time to acquire necessary programming capabilities or communicating the problem to someone with sufficient programming skill. Neither of these alternatives is attractive and the problems connected with each discourage many potential users of simulation techniques.

An alternative that has been utilized successfully in the past is to develop a language oriented to the user rather than the computer. Examples of successful user-oriented languages such as FORTRAN, COMPTRAN and COBOL abound in the general computing field. Under this philosophy a programming language resembling one with which the user is familiar is developed to permit expression of the problem without extensive computer knowledge. It is apparent that if simulation is to become a tool readily available to traffic workers, a language to facilitate the programming of simulation problems by those unfamiliar with computing machinery is needed.

The present system, SIMCAR, has been written for the IBM 709 and 7090 computers, both of which are high-speed digital computers that utilize the binary number system for internal computation and logical operation. Both have 32,768 "words" of magnetic core storage with each word containing 36 binary positions or "bits." The core storage serves as a repository for the program (instructions for the computer to perform) and information used by the program. In the SIMCAR system, the latter consists of parameter tables and sets of vectors that represent the highway, the vehicles, and driver elements used in the simulation. Each decision element, behavior routine and utility program is an individual series of instructions sequentially informing the computer of the processing steps to be followed.

The SIMCAR system consists of three major sections:

1. The translator that decodes the user's problem statements, sets up the necessary parameter and vector tables, and calls in and links together the routines required for a particular problem.
2. The model which is a set of programs coded in machine language assembled by the translator to actually perform the simulation.
3. The output generators that selectively sample specified elements within the highway system and format them for report purposes.

MODELING PHILOSOPHY

The philosophy on which the model is based is relatively simple in principle, but involves complex programming for its implementation. The basic premise is that all drivers have a speed at which they would prefer to travel if conditions meet certain minimal requirements. Acting to limit the driver in pursuit of his desired speed are obstructions generated by interactions with other vehicles and the physical environment. A common class of obstructions are vehicles moving at a slower speed, coupled with either approaching vehicles in the opposite channel or restrictions on the sight distance ahead imposed by the topology of the highway. Other limitations encountered are legal restrictions on speed and passing, grades, the radius of curves and characteristics of the car itself such as its acceleration capabilities.

Desired speed is an abstraction (carried within the computer in f.p.s.) that represents the desire of an individual to move from point A to point B within some specified period of time. For convenience it is expressed as the speed at which a driver must travel if he is to satisfy the time requirements of his trip plan. In our model this element is assumed to remain constant during any single trip, even though circumstances may combine to force a driver to travel at a much slower rate. Thus, the model represents a process in which individual vehicle-drivers continuously seek to achieve their desired speed. Each limiting situation encountered is met (and dealt with) by the driver according to some set of rules. The driver-vehicle makes decisions to abandon temporarily or to maintain his desired speed based on the element of risk he must assume if he pursues his desired course.

The strength with which an individual will strive to maintain his desired speed depends on both his willingness to accept risks as well as the capabilities of the vehicle he is driving. The model assumes that there is considerable differential in the amount of risk that individual drivers will accept. Thus, one driver may find an open sight distance of 800 ft adequate to attempt to pass a vehicle. Another driver in an identical vehicle might conclude that the hazard is too great and decline an opportunity to pass even though they both desire to travel at a higher speed. This difference among drivers in accepting a risk to reach their desired travel speed we have identified as a "valor" factor.

All simulation techniques that utilize the capabilities of a digital computer have certain characteristics in common. Vehicles must be represented numerically within the computer. A set of vectors specify characteristics (length, type of vehicle, etc.) required to adequately represent the vehicle's operating characteristics.

The SIMCAR system uses four vectors to represent the highway, vehicle, driver and control elements. A highway vector comprising 10 components is used to describe each 16 ft of the physical highway. A vehicle characteristic vector with 5 components de-

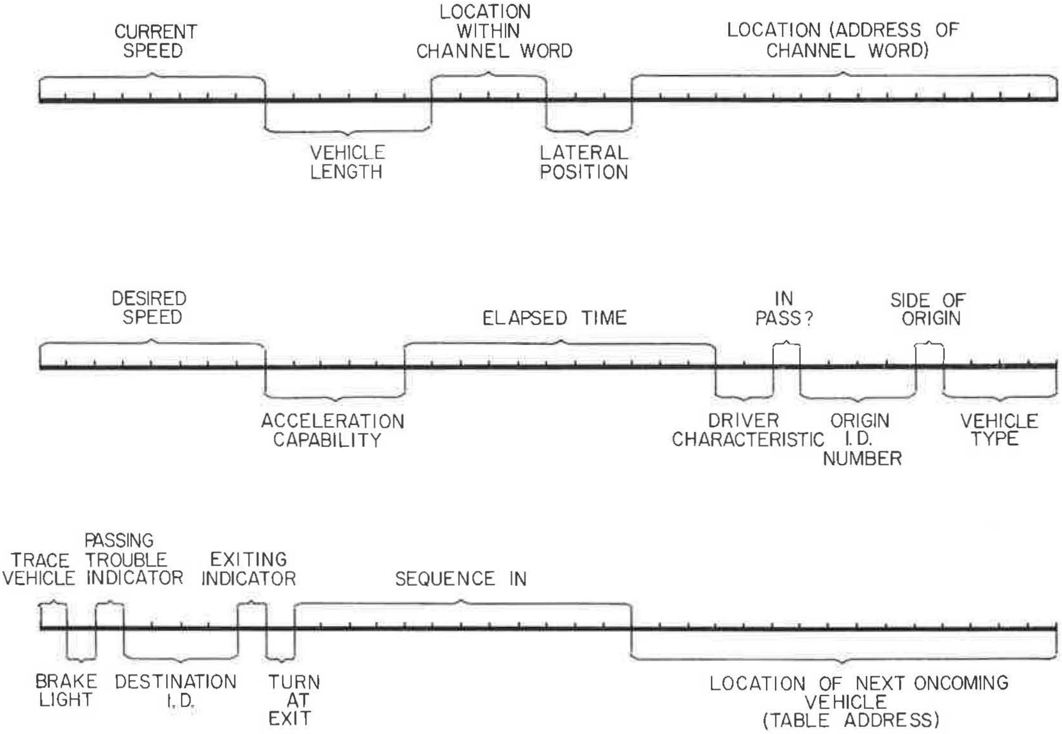


Figure 1. Vehicle representation—3 computer words = 1 vehicle.

scribes the invarient characteristics of each vehicle. A 2-component driver characteristic vector describes the invarient characteristics of the driver. A "state" vector containing 10 components describes the status of each vehicle at the end of each 1-sec interval of time. The physical location of the vehicle on the roadway is specified by three components: the address of the "channel" word in which the vehicle is located, the location within the channel word to the nearest foot, and the lateral positioning. Additional components of the state vector describe current speed, elapsed time, braking, passing, and an index to the next oncoming vehicle.

The vehicles present in the highway image at any one time are carried in two vehicle tables. A separate table is used for each of the two highway lanes. Three computer words are required to carry information that describes a single vehicle. Information is packed into computer words to permit 20 different items of information to be carried for each vehicle. These items are the vehicle, driver, and state vectors that were described previously.

The physical environment or the "highway image" is represented by a set of sequential computer words. A single word is used to contain information for each 16-ft segment of each lane to be present in the simulation. Moving through the computer's memory from one word to the next is the same as going from one 16-ft segment of highway to the next. The highway image is divided into 2 sets of words corresponding to the 2 lanes of the road. Each channel word is a vector that describes the physical environment of that section of the roadway.

The speed limit component is normally an indication of the legal limit imposed on this segment of the road. If, however, the roadway at this point is a curve, the speed limit may be the maximum speed at which a vehicle may maneuver through the curve without skidding. The type of limit and the presence of a curve are indicated by components of the vector. The sight distance component indicates the amount of roadway ahead which would be visible if a vehicle were located at this point in the highway image. The road acceleration vector is determined by the grade and is carried as acceleration capability when in this region.

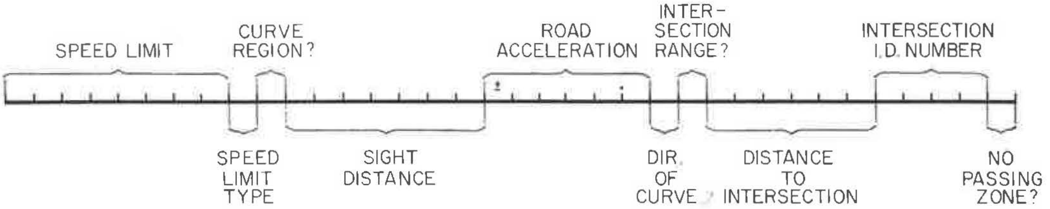


Figure 2. Road image—1 computer word = 16 ft of 1 lane.

When the word represents a portion of a curve the direction of the curve (left or right) is indicated. Channel words representing the roadway leading up to an intersection carry two pertinent facts, the distance to the intersection and an identification number assigned to the intersection by the system. No-passing zones are indicated by the presence or absence of a bit in a specified position of the channel word. Numeric values for each component of the vector are assigned during the SIMCAR language translation phase from the specifications contained in the source language. A great deal of precomputing is carried out during translation to save time during the simulation itself. For example, the user's specifications of grades are converted from percent grade to road acceleration effects and sight distance restrictions. Curve specifications reduce to values of critical speed, sight distance, and passing prohibitions.

Because the highway vectors refer to discrete 16-ft segments, certain approximations must be made. Sight distance, for example, is not carried to the nearest foot, but in terms of number of visible channel words ahead. Distance to an intersection is carried in a like manner. These approximations not only save space within the channel word, but correspond closely to the inability of a driver to estimate distances with any greater accuracy. Regardless of the location of a vehicle within the 16-ft segment, the vectors and thus the environment perceived by him will be the same.

THE SIMULATION PROCESS

The process of simulation itself involves: (a) the determination of when a vehicle is due to arrive at an entrance; (b) the generation of vehicles; (c) the generation of drivers; (d) the movement of vehicles through time and space; and (e) sampling of desired data and its preparation for output.

The number of vehicles to be generated per hour (on the average) at each entry point is carried in the computer as a fraction representing the number of vehicles per second, i.e., the probability of an arrival during any one second. The method used to select interarrival gaps is the "rejection" technique of generating random realizations from a negative exponential distribution. The arrivals are thus Poisson distributed. Random numbers are generated sequentially from a rectangular distribution on the unit interval (0, 1). Each is compared against the arrival probability and the number is rejected if greater than the probability. If the i^{th} number is not rejected (therefore lower than the test value) the next interarrival gap is made equal to i seconds. This determines the time gap until a vehicle is to be generated for entry at this point. At the end of this interval a vehicle will be generated, entered into the system, and another interarrival gap computed.

An actual vehicle on the highway is a physical entity. It has mass, acceleration capabilities, color, a certain shape, and numerous other characteristics which make it unique. Within the computer, each vehicle must be represented by a limited number of numerical abstractions. In the SIMCAR model, each vehicle is represented by a three component vehicle characteristic vector: (a) its length; (b) its capacity to accelerate; and (c) the type of vehicle it is.

These three components are the invarient elements necessary to represent the vehicle for simulation purposes. A set of state vectors represent the state of the vehicle second by second as it moves through the system.

For the model to operate, vehicles must be generated and entered into the system at both the main highway endpoints and any intersectional stubs. The characteristics of these vehicles must vary and be unpredictable on an individual basis, yet capable of specification when taken as a whole. It is worthwhile describing in some detail how the values for each component of the vehicle characteristic vector are generated since the techniques described are used repeatedly in the model.

When a vehicle is due to enter one of the entry points of the system, a pseudorandom number is generated. This number is used to select a vehicle randomly from a distribution of vehicle types previously specified by the user. The value of the vehicle type is entered into the appropriate vector location within the vehicle table word. Next the length and acceleration components are generated, using a slightly different approach. A random number is generated from a rectilinear distribution and transformed to a random draw from a normal distribution whose mean and variance has already been specified by the user.

At the time that the vehicle characteristic vector is generated it is necessary to generate a driver characteristic vector. The driver vector has two components—desired speed and valor factor. Both of these components are abstractions that represent the influence of a group of elements. Valor represents the degree of persistence with which a driver will strive to overcome obstacles and achieve his desired speed. It reflects such things as an individual's basic propensity for taking risks, driving experience, basic driving skills, as well as the strength of the incentive which causes him to seek to reach his destination within a specified time. Desired speed and the variables that it represents have been previously described.

The assignment of values to these two components of the driver characteristic vector is similar in method to the technique described for generating the vehicle characteristic vector. The value of the valor component is determined by using a random number draw from a user defined probability distribution. The desired speed is obtained from a random draw from a normal distribution of speeds with a mean and variance specified by the user. When numeric values have been assigned, all components of the vehicle and driver characteristic vectors are placed in their assigned positions within the vehicle table words.

The state vectors are initialized to their proper values. An actual velocity equal to the desired speed of the driver is used as an initial setting for each vehicle entering at the end-points of the highway. Before the vehicle is allowed to enter the model, the immediate environment is scanned to determine whether entry must be delayed. A vehicle, at one of the two end-points, may have to be entered at a reduced speed where a vehicle traveling at a considerably lower speed has been entered the previous second. In some cases entry must be delayed and the vehicle is placed in a waiting queue until it can enter safely. Vehicles generated at intersections enter the main highway only when a minimum acceptable gap is determined by a stochastic decision process dependent on the vehicle acceleration capability, length, and the driver valor factor.

The simulation of 1 sec of time corresponds to updating the state vectors for each vehicle within the tables. Updating occurs sequentially starting with the most recent vehicles to enter the system and proceeds through the oldest entries. This method of moving from the rearmost to the foremost vehicles in the system provides a fixed 1-sec reaction time, since vehicles ahead have not yet been moved and the vehicle being updated cannot react to their behavior until 1 sec later.

The updating procedure for each vehicle follows a fixed sequence. The vehicle table words are unpacked and the state vector examined. The location components of the state vector are analyzed to determine the vehicle position in relationship to the physical environment. From this information the physical characteristics of the highway are extracted and made ready for analysis. The remaining components of the state vector are scanned to ascertain the condition of the vehicle and the type of behavior in which it is engaged. The vectors that describe the highway are scanned and the vehicle is classified as being in one of the five general categories: (a) free flow; (b) following; (c) passing; (d) exiting; and (e) skidding.

Depending on the general state of the vehicle, the simulator then enters its decision-making phase to determine what action the vehicle will take during the next second of simulated time. After the decisions have been made, their effect on the state of the vehicle at the end of the second is computed. The state vectors are modified to reflect this new status and repacked into the vehicle table word. This procedure is repeated with each of the vehicles until all vehicles in the system have been updated.

Perhaps the updating process can be understood by examining in detail the decision-making process encountered when a vehicle is found to be in free flow status. This involves one of the least complex decision nets.

Decision making, in this case, is limited to determining the acceleration that the vehicle will undergo during the next second of time (${}_a\ddot{X}_n$). There are several variables that enter the decision process. The desired speed (${}_d\dot{X}$), the actual speed (${}_a\dot{X}$), the speed limit (${}_L\dot{X}$), all of which have been described elsewhere in this paper. The grade of the highway (${}_r\ddot{X}$) expressed as an acceleration capability and the acceleration capabilities of the vehicle (${}_v\ddot{X}$) also enter the decision network. The driver factor (D) described elsewhere also appears. The term ϵ (a, b) which appears in the formula is a random normal variable with a mean a and standard deviation b and represents the variation in speed observed when there are no other restricting or inhibiting influences in the surrounding environment.

The following symbolic presentation of the free flow decision network is intended to illustrate technique rather than to serve as a definitive exposition of the structure of the model. As such, no attempt will be made in this paper to justify the constants used except to point out that they were derived from empirical data.

If ${}_d\dot{X} \leqq {}_L\dot{X}$

$$
{}_a\ddot{X}_t = \begin{bmatrix}
\left(\dfrac{{}_d\dot{X} + 43 - {}_a\dot{X}}{{}_d\dot{X} + 20}\right) \cdot \dfrac{16\,{}_v\ddot{X}}{{}_a\dot{X}} + {}_r\ddot{X} + \epsilon(0,\ 0.7) & {}_a\dot{X} \leqq {}_d\dot{X} \\[2ex]
\dfrac{\left({}_d\dot{X} - {}_a\dot{X}\right)^2}{50} + {}_r\ddot{X} + \epsilon(0,\ 0.7) & {}_d\dot{X} < {}_a\dot{X} \leqq {}_L\dot{X} \\[2ex]
\dfrac{\left({}_d\dot{X} - {}_a\dot{X}\right)^2}{25} + {}_r\ddot{X} + \epsilon(0,\ 0.7) & {}_d\dot{X} < {}_L\dot{X} < {}_a\dot{X}
\end{bmatrix}
$$

If ${}_d\dot{X} > {}_L\dot{X}$, let

$$
{}_e\dot{X} = \frac{{}_d\dot{X} - {}_L\dot{X}}{4}\, D + {}_L\dot{X}
$$

$$
{}_a\ddot{X}_t = \begin{bmatrix}
-3 + \epsilon(0,\ 0.07) & {}_a\dot{X} < {}_e\dot{X} \\[2ex]
\dfrac{{}_e\dot{X} + 43 - {}_a\dot{X}}{{}_e\dot{X} + 20} \cdot \dfrac{32\,{}_v\ddot{X}}{{}_a\dot{X}} + {}_r\ddot{X} + \epsilon(0,\ 0.7) & {}_a\dot{X} \leqq {}_e\dot{X}
\end{bmatrix}
$$

The location of the vehicle, its actual speed and other components of the state vector are calculated for the vehicle at the end of the second and the new values are entered in the vehicle table.

During the time the model is being updated sampling information is being collected in accordance with instructions provided by the user. For example, the user may have asked for volume counts at several locations on the highway. Every time a vehicle passes one of the specified points, a count is made and retained until it is time for the data to be written out. A wide variety of measures can be sampled on a selective basis including spot speeds, travel speeds, headways, passing, delay times, queue counts and volumes. In addition, second by second traces of individual cars can be obtained. How measures that are to be sampled are specified is explained in the section on language.

The basic modeling concepts remain the same for all simulations; however, each separate simulation has different parameters, vectors, vector functions, sampling requirements, reports, and control elements. Thus it must be possible to specify these elements quickly.

ELEMENTS OF THE SIMCAR LANGUAGE

The SIMCAR language was designed to resemble the language and notation commonly used by traffic engineers. It offers sufficient flexibility to permit complete and precise specification of simulation problems, yet it is simple enough to be mastered in one or two days of training. It permits the user to describe the highway configuration, the vehicles that use the highway, the drivers, and necessary control elements in a language similar to that with which he is accustomed.

A SIMCAR source program consists of a sequence of statements of which there are 21 types. Each SIMCAR statement is punched into a separate card for entry to the computer. The 21 statements available to the SIMCAR user may be classified into six categories, as follows:

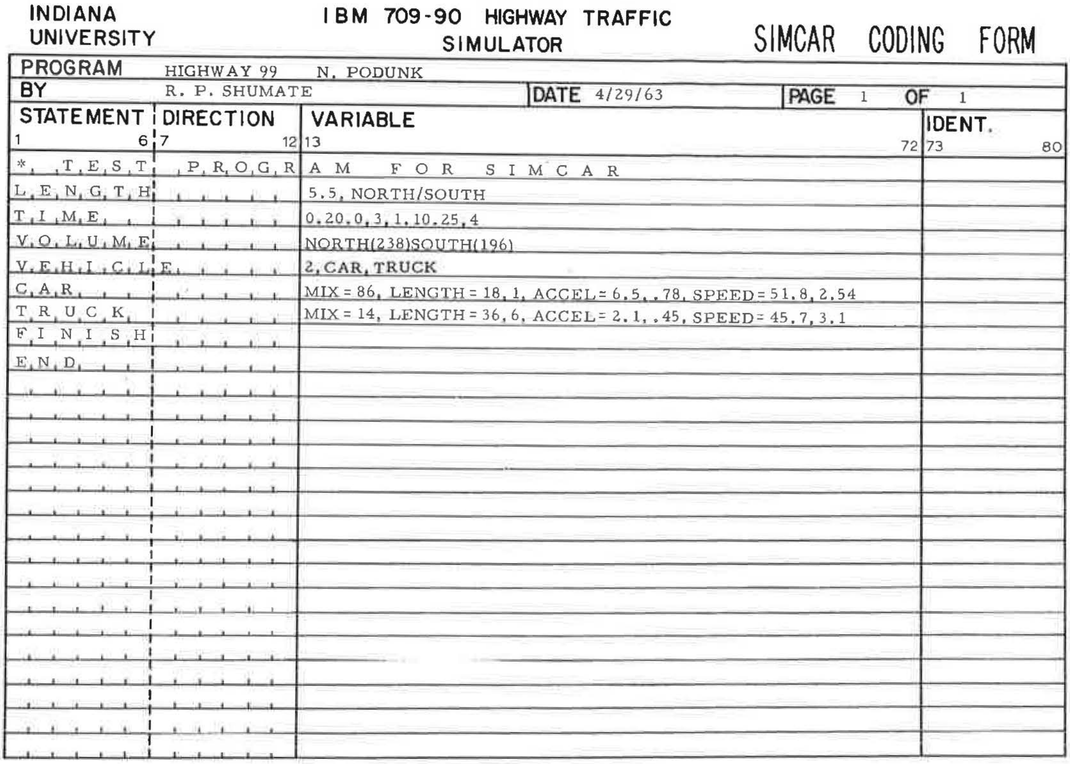
1. Highway Configuration statements permit definition of all pertinent physical characteristics of the highway to be represented.
2. Vehicle Specification statements permit definition of the physical characteristics of vehicles to be represented along with a specification of the mixture of different general types desired.
3. Driver Specification statements make it possible to define the mixture of driver characteristics desired for each of the vehicle types.
4. Control Statements perform miscellaneous functions, such as specification of speed limits, no-passing zones, simulation time segments, and signal descriptions.
5. Report Generating Statements are used to specify the type and content of output reports.
6. Specification Statements are used to delineate different segments of the SIMCAR program. They are used to define the beginning or end of a segment of the total program.

It will not, within the limits of this paper, be possible to describe all statement types in detail. At best, the discussion will be limited to examples that are typical of the statement types available and which illustrate their functions.

Perhaps the best way to proceed is to describe the set of statements required to produce a minimum SIMCAR program. A simple problem can be programmed using only six different statement-types. As more complexity is introduced into the highway topology, traffic, or output, additional statements must be used. A minimum program must contain at least the following statements: identification statement, length, time, volume, vehicle, and end.

The length statement fixes the length of the highway to be simulated and assigns names to the two directions of flow for later reference in the program. A $5\frac{1}{2}$-mi segment of highway running in a general direction which the user may wish to define as North and South would be specified as follows:

```
LENGTH          5.5,  NORTH/SOUTH
```



INDIANA UNIVERSITY | **IBM 709-90 HIGHWAY TRAFFIC SIMULATOR** | **SIMCAR CODING FORM**

PROGRAM HIGHWAY 99 N. PODUNK
BY R. P. SHUMATE | **DATE** 4/29/63 | **PAGE** 1 **OF** 1

STATEMENT 1–6	DIRECTION 7–12	VARIABLE 13–72	IDENT. 73–80
* TEST	PROGR	AM FOR SIMCAR	
LENGTH		5.5, NORTH/SOUTH	
TIME		0.20.0,3,1.10.25,4	
VOLUME		NORTH(238)SOUTH(196)	
VEHICL	E	2, CAR, TRUCK	
CAR		MIX = 86, LENGTH = 18, 1, ACCEL= 6.5, .78, SPEED= 51.8, 2.54	
TRUCK		MIX = 14, LENGTH = 36, 6, ACCEL= 2.1, .45, SPEED= 45.7, 3.1	
FINISH			
END			

Figure 3. SIMCAR coding form with sample program.

Because this statement allocates internal computer storage for the highway image it must be the first statement of any SIMCAR program.

The time statement is used to control the number and length of the intervals to be simulated. This permits segmentation of a long run to allow several sampling periods. The accumulated results of the simulation can be output at the end of each interval. A problem to simulate three 20-min periods followed by four periods of 1 hour, 10 minutes and 25 seconds would be written as follows:

```
TIME        0.20.0,3/1.10.25,4
```

The time statement is a control statement required for all programs.

The volume statement is used to specify the average rate of vehicle entry into the highway from the two endpoints. It is expressed as vehicles per hour for each of the two lanes of traffic. If the Northbound flow desired was 238 vph and the Southbound flow 196, the statement would look as follows:

```
VOLUME        NORTH(238)    SOUTH(196)
```

Since the actual arrivals are stochastically determined the specified volume rates will satisfy their average only during a lengthy simulation.

The vehicle statement is actually a set of statements used to define the mixture and physical characteristics of vehicle types to be represented in the flow. They also specify that portion of the driver characteristic vector pertaining to desired speed. The vehicle statement itself defines the type of vehicles that will be present in the traffic flow by assigning a symbolic name to each vehicle type. For each vehicle assigned a symbolic name a subsequent statement must appear within the range of the vehicle statement specifying the parameters for that vehicle. The range of a vehicle set is determined by the finish statement.

To illustrate: a mixture of two vehicle types for both lanes of traffic would require a vehicle definition statement, two defined vehicle statements, plus a finish statement. Assume that the two vehicle types are to be called car and truck with parameters as shown, then the statement set would appear as follows:

```
VEHICLE   2, CAR, TRUCK
CAR       MIX = 86, LENGTH = 18,1, ACCEL = 6.5,.78, SPEED = 51.8,2.54
TRUCK     MIX = 14, LENGTH = 36,6, ACCEL = 2.1,.45, SPEED = 45.7,3.1
FINISH
```

Since no reference is made to directions the specifications are assumed to apply to both lanes of traffic. If the vehicle characteristics are to differ between lanes, each lane must be defined separately. The names car and truck are arbitrary creations and have symbolic meaning only.

The second and third statements define parameters for car and truck, respectively. Each statement has four sets of elements within the variable field. The first element MIX specified that 86 percent of vehicles entered into the system will be of the type defined as car and 14 percent will be truck types. In each of the remaining three sets of elements, the first numeric value encountered to the right of the = sign is the mean and the second value is the standard deviation. The alphameric portion to the left of the = sign defines the particular parameter. Thus the variable field sets the parameters for the length, acceleration capabilities, and desired speed of each vehicle type defined. The finish statement is used to inform the SIMCAR translator that the end of the vehicle statement set has been reached.

The end statement which consists of the word end in the statement field with blanks in the direction and variable field, defines the end of all user specifications. The end statement is used to signal the translator that the end of a SIMCAR translation has been reached.

With just those statements already discussed a program to simulate a simple highway can be specified with many assumptions being made by the model concerning unspecified vectors. The roadway would be perfectly straight and flat with no intersections, signals, speed limits, or no-passing zones. The coefficient of friction between tires and pavement would be 0.67. Driver valor factors would be drawn from a distribution that assign a probability of 0.15 for both the highest and lowest risk-taking category, with the two middle groups having a probability of 0.35.

Additional statements can be used to specify additional elements of the highway, vehicle, driver and control elements that are required. They can also specify what events are to be measured and the form in which they will be reported. The function of the remaining statements will be described briefly.

The following statements affect the highway geometry:

Curve—defines the location and physical characteristics of any curves desired.

Grade—indicates the location and grade of all non-level segments of the highway.

Limit—introduces "legal" speed limits into any specified segments of the highway at the level indicated.

No pass—places arbitrary no-passing zones in the lanes and locations specified.

Weather—introduces regions where the coefficient-of-friction between the roadway and vehicle tires is other than the standard 0.67.

Intersection—identified the location and configuration of any "stubs" where traffic may enter and exit and where signals may be placed.

Several statements relate to the driver and highway control elements and are used as follows:

Driver—defines some probability other than the 15, 35, 35, 15 standard for the driver valor factor.

Signal—places a signal at an intersection with length and synchronization of all phases and the phasing with other signals specified by parameters.

Intersection--"stub" statements—specify the average volume of all portions of the traffic flow entering and exiting at the indicated point.

The remaining statements in the language specify events that are to be measured and the type of reports that are to be generated. Any combination of the following may be selected by the user:

Map--causes the printing of all or part of the highway image contained in the computer. A line of information is printed for each channel word or 16-ft segment listing the values of all vector components of the highway topology.

List--causes the printing of a report listing and labeling the values of all vector components, traffic volumes, and timings specified by the user. This provides a record of the particular simulation being performed.

Retired Vehicle List--causes the listing of all vehicles which exit at intersections.

Trace—provides for the flagging of vehicles according to any of ten criteria. Each vehicle so flagged will have printed for it a report that gives a second-by-second history of its state vectors during its life in the simulation. Additional capabilities permit tracing vehicles only during the time they are traveling over specified segments of the road. Alternatively the language permits the user to specify that only vehicles in some states (such as passing, skidding, and exiting) are to be traced. This capability corresponds to the widely used method of sending "floater" vehicles through the segment to be tested in order to measure the qualities of the traffic flow.

Sample--enables the user to place any number of sampling points along the roadway at which any number of the components of state vectors of passing vehicles may be extracted and summarized according to several available processing functions. Frequency distributions, plots, statistics, and lists may be compiled selectively for any of the sampled items. This facility corresponds to practice of placing equipment at spot locations along a roadway to observe the characteristics of the traffic flow at that point.

Wreck—permits the user to indicate the procedure to be followed in case of an accident during simulation and also permits definition of near-wreck situations for listing or summarization as a measure of the quality of the traffic flow.

Structure of the System

SIMCAR is a completely self-contained programming system. As such, it contains the following significant divisions of system programs: (a) the executive program, (b) the translator programs, (c) the simulation programs, (d) a relocatable loader, and (e) a library of relocatable programs.

Physically the system is contained on a system tape and a library tape. Once these two tapes are mounted on their proper drives, operation becomes automatic.

The executive program is brought into core at the start from the system tape and remains there as long as the SIMCAR system is being used. Its function is to monitor the performance of the entire system, bringing in and linking together segments of the system as needed. When the system is ready for use the executor brings in the translator program to translate the user's statements into the form required by the simulation model.

```
  TRACE OF CAR        IN NORTH  BOUND LANE.  30  VEHICLE FROM        ENTRY  SIDE.

LENGTH =    20     DSPD =   58.6  VACC     =     7.5 DRIVER    =  4
        VELP  ADIS  ASPD  XCHG  CPEN STRDL  ACCL  STRDP  LENP  SEQP  TURN  MCLK
        44.3   541  58.6        2032        -0.0           19    29          68
        43.6   520  58.6        2032   1     2.0           19    29          69
        43.6   497  60.0        2032          .5           19    29          70
        42.9   473  60.0        2032   1     2.0           19    29          71
        42.9   447  61.3        2032          .0           19    29          72
BRAKE   41.6   419  61.3        2032        -1.0           19    29          73
        43.6   391  60.6        2032        -0.5           19    29          74
        42.9   366  60.6        2032   1     2.0           19    29          75
        42.2   339  62.0        2032          .5           19    29          76
        44.3   311  62.0        2032   1     2.0           19    29          77
        43.6   284  63.4        2032        -2.0           19    29          78
        43.6   256  62.0        2032        -1.5           19    29          79
        42.9   229  61.3        2032   1     2.0           19    29          80
        42.9   201  62.7        2032   2      .0           19    29          81
BRAKE   41.6   171  62.7        2032   3    -3.0           19    29          82
        41.6   141  60.6        2000   4      .5           19    29          83
        41.6   113  60.6        1856   4      .5           19    29          84
        41.6    85  60.6        1712   4      .5           19    29          85
        41.6    57  60.6        1568   4      .5           19    29          86
        41.6    29  60.6        1424   4      .5           19    29          87
        41.6     1  60.6        1280   4    -2.0           19    29          88
        41.6   -26  59.3        1120   4    -1.0           19    29          89
        41.6   -52  58.6         976   4    -0.0           19    29          90
        46.3   538  58.6         816   3     2.5           18    28          91
        45.6   519  60.0         656   2    -1.0           18    28          92
        45.0   498  59.3         496   1    -0.5           18    28          93
        44.3   477  59.3         336          .0           18    28          94
        43.6   455  59.3         176        -1.5           18    28          95
        42.9   432  58.6          16        -1.0           18    28          96
        42.9   409  57.9          96        -1.0           18    28          97
        42.9   387  57.2         112        -2.5           18    28          98
BRAKE   41.6   366  55.9         -32        -1.5           18    28          99
        40.9   345  55.2         224        -3.0           18    28         100
BRAKE   38.1   323  53.1          80        -2.0           18    28         101
BRAKE   35.4   300  51.8         272        -2.0           18    28         102
BRAKE   34.0   276  50.4         160        -1.5           18    28         103
        33.4   252  49.7          48        -1.5           18    28         104
        32.7   228  49.1         -48        -1.5           18    28         105
        32.0   204  48.4          64        -1.5           18    28         106
        31.3   180  47.7         -32        -2.0           18    28         107
        31.3   157  46.3         -16        -2.0           18    28         108
        31.3   136  45.0          16        -2.0           18    28         109
        32.0   117  43.6          16        -2.0           18    28         110
        34.7   103  42.2          48        -1.0           18    28         111
BRAKE   33.4    91  41.6         -32        -1.5           18    28         112
        32.7    79  40.9         -16        -2.5           18    28         113
        32.7    68  39.5          48        -3.0           18    28         114
        32.0    59  37.5         -32        -3.0           18    28         115
BRAKE   30.6    51  35.4                    -4.0           18    28         116
BRAKE   28.6    45  32.7         560        -3.0           18    28         117
        28.6    40  30.6         448        -2.0           18    28         118
        30.6    39  29.3         320        -1.0           18    28         119
BRAKE   28.6    40  28.6         224        -0.0           18    28         120
        30.0    41  28.6         112         1.0           18    28         121
```

Figure 4. Trace of single vehicle showing state at end of each second.

When translation is complete the executive program then calls in the simulation program. At the same time the executive routine calls in the relocatable loading program, goes to a library of relocatable report generating and sampling routines, and brings those programs necessary for sampling the data requested.

When all subroutines required for simulation have been placed in core with the necessary linkages, the executive routine then releases control to the simulation model itself. When the simulation is complete, routines necessary to output the generated data are called in and the reports requested are written on the output tapes. The executor then determines whether there are additional problems to be run. If so, it calls in the translator to begin the cycle over again.

One advantage of having SIMCAR operate as a complete programming system is that it permits fairly long highway segments to be simulated. The length of the facility that may be simulated depends on the internal computer storage available. By using only those parts of the systems needed at any specific phase, core is more efficiently used. Storage space required for the translator may be reused to contain the model during the simulation phase. In turn the output routines necessary to generate the reports can occupy the space used by the simulation model since output normally does not take place until the simulation is complete.

MODEL VALIDATION

Normally, digital computer simulation is used to study a facility that either does not exist or to test a condition that cannot be created on an existing facility. The user expects the results of the simulation to approximate the performance of the system he is studying if the actual system could be observed. The question of validity is then an important one.

This question must be answered: "Does the simulation model produce results consistent with what would be found on an actual highway with the same physical characteristics?" Results obtained from simulation of a highway facility are particularly susceptible to doubt since they are generated by the manipulation of numerical values within the computer rather than by physical means.

The simplest and most direct means of validating a traffic flow model is to obtain measurements from an actual operating highway facility, model the facility in the computer, and compare the output of the model with that collected from the actual flow. There are, however, several philosophical questions encountered in the model validation that are difficult to resolve. The most troublesome is the question of what criterion should be used to define an acceptable level of consistency between the simulated and real system.

The most obvious approach is to use tests of statistical significance to compare the two sets of measurements. A criterion of acceptance is one in which the two sets of measurements are found to be from the same population or the form of their distributions do not differ significantly. Another criterion is one of reasonableness in which the comparison between the real and simulated system is based on the use to which the simulated output will be put. Detailed examination of the simulated behavior of vehicles as they pass, move into queue or stop at intersections can reveal whether the behavior is plausible.

What elements should be measured for validation purposes? We have selected those for which there is adequate data from real highway systems against which comparisons can be made. Specifically, points of validation that are being used are as follows:

1. Spot speeds, including mean, variance, and comparison of distributional form for samples drawn from the simulated and real system.
2. Headway distributions.
3. Travel speeds between selected points ranging from ¾ to 3 miles in length. Comparison is made of means, variance and distribution.
4. Passing frequency for segments of highway ranging in length from 1 to 4 miles.
5. Distribution of queue lengths at various points.
6. Volume of different types of vehicles.
7. A comparison of the second-by-second vehicle traces generated by the model with performance data collected from test vehicles moving through traffic.

Validation of the SIMCAR model is now in progress and will continue to be for some time to come. Detailed data on over 200,000 vehicles from 135 miles of highway in southern Indiana have been collected. The data include measurements of headways, travel speeds, spot speeds, passing rates, queue lengths, and vehicle types. Validation work now in progress consists of simulating models of the highway sections from which the real data were collected and comparing the generated and the real data. Thirty different highway configurations ranging in length from 1 to 4 miles are being used for validation. These sections include nearly all variations and combinations of highway and vehicle elements encountered on 2-lane rural highways. Thus if the distribution of spot speeds drawn at 30 different highway locations show statistical correspondence, there is some basis for concluding that the model will produce realistic speeds for any configuration subsequently encountered.

Most of the completed validation has been based on the criterion of reasonableness. Much of the work has involved comparison of generated and real data by means of graphs. Frequently these results have led to modification of certain elements of the model. During the next year increasingly more rigorous tests will be applied to the data. However, the initial tests have been encouraging and it appears that the simulations now being performed closely approximate the real situation.

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Discussion

S. L. LEVY, M. CARTER, and J. SCHEU, Midwest Research Institute, Kansas City, Missouri—The authors should be commended for their effort directed toward the development of a general purpose traffic flow simulator. The potential uses for a model capable of simulating such a wide variety of geometric and traffic flow conditions are certainly obvious to anyone involved in traffic research. The ease with which a problem can be set up and the variety of flow characteristics that can be recorded are properties of SIMCAR that will be extremely valuable when the model is used for traffic studies.

It is evident that their paper summarizes a vast amount of work, and there was certainly no way for them to discuss every topic at length. However, we would have preferred more emphasis on model logic and less on programming detail. For example, the logic used to determine whether a vehicle can merge is of greater interest than the fact that "no-passing zones are indicated by the presence or absence of a bit in a specified position of the channel word." The inclusion of flow diagrams would have been helpful.

We now know that traffic simulation "works," in the sense that a computer can be made to "move" vehicles in a manner apparently similar to a real traffic. This can be verified by tracing the path of a car (a SIMCAR option), by dumping the location of vehicles after each time increment, or by viewing an oscilloscope which is used in conjunction with some simulations. What we do not know, or at least what we have not verified, is the fundamental logic which must be used to simulate traffic accurately. For this reason, we must tell one another what we believe this logic to be, as well as the reasons for so believing. The model itself, quite apart from any computer application, should receive more attention.

The concept of a "valor" factor is intriguing and could well be the basis of a lengthy discussion. When using such a factor, it is tacitly assumed that a driver who performs one function "bravely" will also perform similar functions bravely, i.e., a driver who will pass when only a short sight distance is available will also hurry to beat a red light. One could also define factors which are measures of an individual's ability to perform functions accurately and/or rapidly. These factors are not limited to traffic simulations but could be used in any model requiring a consideration of human factors.

This technique makes it possible to define an individual's behavior with a smaller number of parameters. Input preparation is simplified, less computing time is devoted to parameter assignment, and it is easier to interpret results.

There is also a disadvantage. Although it is undoubtedly true that behavior parameters are correlated, the connecting equations are usually unknown. If an invalid equation is chosen then no amount of parameter adjustment will give realistic results. Prior to thorough testing, one does not guarantee that a model will give valid results. However, the use of such things as a valor factor would seem to increase the risk of failure.

One's attention is frequently caught by a single statement. Often the proposition is neither profoundly true nor obviously false; just interesting and debatable. The following is an example of such a remark: "The most serious obstacle to removing traffic flow simulation from the category of an experimental technique is the lack of a suitable programming language." Quite properly, the authors would like to see traffic simulation made available to people who are not programmers. They believe that simulation can be used to help solve the practical problems faced by traffic engineers. Furthermore, they suggest that SIMCAR is the language which can bring this about.

We would like to raise three questions:

1. Does SIMCAR truly constitute a programming language?
2. Is there really a need for a special traffic simulation programming language?
3. Are there not more serious obstacles to be surmounted before traffic simulation finds wide acceptance?

Perhaps there is confusion as to what constitutes a programming language. Surely, SIMCAR is not a language in the same sense as FORTRAN or COBOL. Instead, it could be described as a traffic simulation model with fixed logic and an elegant set of input and output routines. Whereas a statement in one of the commonly used compiler languages will be translated into a set of machine instructions, a SIMCAR statement supplies parameters to the existing simulation routines. This does not detract from the value of the model but it should be understood that SIMCAR is a programming language in a limited sense only.

In our opinion, a traffic simulation programming language would be of little value at the present time since it would not help to alleviate the problem of model building.

An alternative is to develop a few highly flexible programs, written in any language, and makes them available to the general traffic public. (Even today most traffic systems could be simulated on either the TRANS model at Thompson Ramo Wooldridge, the freeway simulator at Midwest Research Institute, or SIMCAR itself.) Surely the input preparation, operating procedures, and output interpretation could be made so simple that they could be learned in one day. The user could concern himself as much or as little as he likes with internal computer operations. This is the direction traffic simulation must take if it is to achieve wide acceptance.

Before closing, we would like to mention three problems which, in light of our experience, form the biggest hurdles that traffic simulation must surmount.

1. We do not know enough about traffic itself, consequently our mathematical models are not always realistic. We sometimes reduce the real world to equations which have no factual foundation. On the other hand, we do an excellent job of converting our models into workable programs. It seems that programming details have received too much of our attention and model development not enough.
2. The second problem concerns validation. The whole area of deciding which data to collect and how to collect them seems very hazy. To what extent must models be statistically equivalent to real traffic systems? Statistically equivalent sounds impressive, but what does it really mean?
3. Once we are convinced that a model is validated, we must still convince other people. Even the potential user who is completely unconcerned with internal computations will insist that the computer output be the same as would be observed on a real highway. Assuming that our goal is widespread usage of traffic simulation, we must find a way of convincing people that it will work.

D. L. GERLOUGH and FREDERICK A. WAGNER, JR., Planning Research Corporation—The authors are to be commended for their comprehensive effort to date, and congratulated on the excellence of this report. There is such a broad range of agreement with the content of the report that it was with some hesitancy that this discussion was undertaken for fear of appearing overly disagreeable or critical. However, it is always more interesting and fruitful to question, discuss, and in the end resolve.

The use of digital computer simulation as a traffic research tool is virtually untapped. At a time when businessmen, defense analysts, scientists, corporate managers, etc., are employing simulation to help them make hard and fast decisions and gain more understanding of complex processes, many in the traffic engineering community fail to consider seriously simulation as a tool for traffic study. Some find it necessary to drape simulation in an aura of mysticism, either out of a lack of understanding or in an attempt to impress, thus causing it to be viewed as impractical.

All of us have been presented with this simple statement of fact, but it is worth reiterating: A computer can do nothing but what it is instructed to do; and further, we could carry out these instructions manually, given enough manpower, paper and pencil, mathematical tables, a coin to toss for random decisions, and unlimited patience. This may all seem too elementary to be worthy of note, but it is a statement which must become more universally believed by traffic workers before the potential applications of simulation can be developed fully. In this spirit, although we agree wholeheartedly with the capabilities of a traffic flow simulator which the authors list, phrases such as ". . . such study is impossible in real life. . ." and ". . . at present, there is no way of determining how a new design will affect traffic flow short of actually building the installations. . ." are cause for mild objection. We could make these studies using the same instructions given to the computer. The computer merely makes the time and dollar costs of such studies low enough to be feasible.

While on the subject of economic feasibility, it would be interesting to attempt to analyze exactly what we mean. If one indicates that 1 hour of XYZ computer time is needed to simulate 10 hours of traffic behavior, we can hardly judge whether the simulation is indeed economically feasible. Rather, we must state the objectives of the study explicitly, compare the alternative techniques for meeting the objectives at our disposal, and then select the technique which does the job effectively at the least cost. When viewed from this standpoint, the use of simulation as a study tool often becomes much more attractive economically.

The benefits to be derived from the development of a general-purpose traffic flow simulation system which is easily used and performs a variety of jobs effectively are certainly apparent. Traditionally, the development of the model and its transformation to a computer program have been costly in relation to the subsequent application of the tool. SIMCAR, it is claimed, would minimize the development cost by providing the engineer with the ability to tailor-make his own simulation easily, in a language not foreign to his nature.

The first item of discussion is the question of how general SIMCAR really is. SIMCAR appears to be a system which already has several fixed features, such as the manner in which the vehicle, road, and driver are represented, and the use of a 1-sec time cycle. At first reading it appears oriented to a single 2-lane highway strip in the rural environment, with intersections considered only with respect to their effect on the "main" highway, and perhaps with greater emphasis on vehicle-road relationships than on intervehicle relationships. What if we want to study a 500 intersection network? The SIMCAR approach is too microscopic for that. On the other hand, if we are interested in studying a single merging area or an individual intersection, we may need more detail than SIMCAR can provide. In any case, we await with interest greater detail about the model of driver behavior. Certainly one can conclude that as reported SIMCAR cannot be applied to the study of a network of streets.

The second and perhaps more basic question is, "Is it really desirable to develop a programming system which can be applied to the study of almost any traffic situation or problem?" Has the obstacle to progress in the application of computer simulation to traffic study been a programming language problem? Is it desirable for the traffic research man to be able to communicate directly with the computer? Are not computer programmers already expert translators of human ideas to machine language? Perhaps better communication between engineers and programmers is what we need. Should not that be easy if both speak English? Once a proper working relationship is developed, cannot existing languages such as SIMSCRIPT (9) provide the necessary relief from some of the programming details?

It is the opinion of the discussors that although making it easy to talk with computers should help us, it is not really what we are after. What the engineer must be able to do is define the problem, both in his own mind and on paper, formulate a systematic plan of research objectives, and model the system about which he should know more than anyone. Then getting "on" the computer—talking with the programmer—will be greatly simplified. Traffic simulations are of such a complexity that a professional programmer should be a member of the team.

In the past, traffic research men have again and again stated how much progress they could make if only they could perform controlled experiments like the botanist or chemist does, holding all the extraneous factors in check so that truly significant conclusions could be drawn. Our new tool, simulation, opens the door to such experimentation. This, it is believed, is the most promising future application of simulation. If easier communication with the machines accelerates such applications, fine; but it is hoped that a rash of haphazard traffic games which will cloud the utility of computer simulation does not result.

This paper's description has illustrated the need for renewed basic research studies of the vehicle-driver-road complex. Driver "valor" is of considerable importance in his model. Yet our knowledge of this characteristic is lacking. For example, there is the question of whether a driver has the same relative degree of valor in different traffic situations. Is the driver who follows close also the one who takes greater risks in passing, or in crossing a stream of traffic; and furthermore, does this driver with great valor accelerate and decelerate rapidly and strive to maintain a relatively high speed? These are pertinent questions to which we have no answers today.

It is hoped that this discussion had not been excessively argumentative; it should in no way detract from the quality of the authors' efforts. More details of their work and the results of the energetic validation activity are anxiously awaited.

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JAMES H. KELL, Institute of Transportation and Traffic Engineering, University of California, Berkeley—The vast amount of effort expended in the development of "SIMCAR" is apparent in this paper, and Messrs. Shumate and Dirksen are to be congratulated in undertaking such a complex project.

Although I would like to discuss many of the operational and logical aspects of the model developed by SIMCAR, I will confine my remarks to a discussion of the reasons for having a simulator as described by the authors.

Their first point is that a traffic flow simulator with generalized capabilities "can provide a means of studying the effect of different types of highway design on traffic flow behavior." This would imply that a highway designer would use simulation to determine whether to use a 2- or 3-deg curve or to use 11-ft lanes instead of 12-ft lanes. I do not feel that simulation techniques will ever be utilized by highway designers to determine the physical design of an individual route. I do believe that simulation is primarily a research tool which can and will be used to evaluate various elements of design which will, in turn, be used to develop policy that governs the design of a given route.

The authors state that a barrier to ready utilization of simulation is the lack of a suitable programming language and imply that with a system such as SIMCAR, the user does not really have to understand the operation of the model. He need only provide factual data concerning the highway configuration and various controls present, and then specify a desired volume and mixture of traffic with some generalized characteristic and behavioral distributions for the different categories of vehicles and drivers. I protest. Any person utilizing simulation techniques must be fully aware of the operation of the simulation model and all the assumptions and limitations inherent in that model. If not, he is going to believe that the computer is taking care of all situations and/or conditions that arise during the simulation (which no simulation model can hope to achieve in the reasonable future). He can very easily draw completely erroneous conclusions from the results.

The second aim is described as "the ability to determine in advance the effect of increased traffic volume on existing facilities. Probable congestion points and accident locations could be anticipated. . . ." In general, locations where congestion will occur with increased volumes can be predicted at present without simulation. I would imagine probable accident locations could also be predicted with some accuracy (although I am not sure that accident occurrence is necessarily related to increased volume). Evaluating an existing facility under increased or future loadings would be a desirable asset to any operating engineer. But this is more than just increasing input volumes to a simulation model. As the input volume changes, so does driver behavior. As a " capacity" condition is reached or the system degenerates into a "forced-flow" condition, the entire facility is unstable. There is relatively little known about driver behavior and response under these conditions, making it extremely difficult to include this type of operation in a generalized model such as SIMCAR.

Providing "a means for studying the effect of control measures on existing highways" is the third application recommended by the authors. At first glance, this appears to be most desirable. There are certain areas, such as progressive signal timing, where simulation can be very valuable, but once again as a research tool. When a simulation model is developed to the extent where a realistic simulation of an urban street is achieved, a comprehensive study will reveal the answers. Once this has been done, the results will be available and can be applied to field situations. It will not be necessary to repeat the simulations for each individual route encountered in the field. It is also problematical whether any generalized flow simulator can have sufficient detail to evaluate the effect of an individual stop sign or the suppression of individual driveways.

The final reason for utilizing such a simulator is that "it would offer a means of studying accidents and near accidents to identify factors relating both to the driver, the vehicle, and their interaction with the physical environment leading to a better understanding of how accidents occur." This, too, appears to be a worthwhile objective on the surface. But, let us examine it in more detail. Assuming an accident rate of 4 per million vehicle-miles, a route that is 10 miles long, and a constant volume of

500 vph, the average spacing between accidents would be 50 hours, or, at the authors' current time advantage of six to one, $8\frac{1}{3}$ hours on the computer. Disregarding this time element, accidents and "near-accidents" (which must be defined) can only occur because of the way the model operates, i.e., the way it has been programmed. Whether or not programmed stochastic events combining at a given time in the simulator actually culminate in an accident whereby useful information can be ascertained is open to question. If sufficient knowledge of driver behavior in an accident situation is available to program the model, the investigation becomes redundant. Until more is known about driver reactions to emergency situations (as is being studied by means of driver simulation), I question the feasibility of utilizing a simulation traffic model to analyze accident causation.

The comments I have presented might imply that I do not believe in simulation. Quite the contrary. In fact, I have devoted a majority of my time over the last several years to development of microscopic simulation models of intersections to evaluate the effects of traffic signals and signal timing. I am very much convinced, however, that simulation is essentially a research tool and, as such, requires the user to be completely familiar with the operational capabilities and limitations of his model.

It is obvious that the authors and their colleagues have expended a great deal of effort on this project. I am happy that this has been possible and that they have gained the necessary support to concentrate their efforts in furthering the knowledge of the simulation field. I can only express my wish that they would expend a greater proportion of their time on developing realistic models to simulate specific elements rather than attempting to achieve a generalized language and translator to include all physical, traffic, and driver conditions.

ROBERT P. SHUMATE and JAMES R. DIRKSEN, Closure—The points raised by the discussants emphasize the many problems that remain unsolved in the simulation field. At present we know far too little about the process of traffic flow. There is very little agreement concerning methods of validation or when a simulation model can be considered to be validated. There are however, some points raised by the discussants that we feel deserve specific comment.

The problem of man-machine communications involves more than a need for engineers to work more closely with computer programmers. Improved verbal communications between engineer and programmer can increase the utility of computers for traffic simulation. Unfortunately the problem involves more than merely communicating needs and ideas from engineer to programmer. Even after the engineer communicates his problem to the programmer, the programmer is frequently unable to structure the problem for machine solution without long and tedious programming effort in a language unsuited to that class of problem.

There is no question that engineers and others who work in the traffic field need to define their problems more precisely. Language availability alone will not remedy this problem but it is reasonable to expect that a language which permits direct communications with the computer may serve to elicit better formulated problems related to traffic flow.

The driver valor factor mentioned by most of the discussants is interesting as an abstract concept but probably does not assume the importance that the discussants have assumed that it does. There is a great deal of difficulty in specifying exactly what the abstraction called "valor" represents. It is intuitively reasonable to assume there exists a factor associated with drivers which represent their propensity for accepting risks in the driving situation. There is a paucity of information available to indicate how this characteristic is distributed in the general driving population. We have recently concluded, however, that other parameters related to the driver, particularly those related to skill, the ability to estimate and perceptive capability are important if models are going to truly reflect the interaction of the driver with his environment.

The SIMCAR language cannot be classified as a programming language in the same sense that languages such as FORTRAN and COBAL are. The SIMCAR program does not generate object code although it does generate code which executes very complicated linkages between the subroutines. It does bring in numerous small subroutines and link them together to form larger programs to meet the requirements of the problem that has been stated. Regardless of whether it can be classified as a programming language, SIMCAR does provide a language structure that persons unfamiliar with computer programming can use to state problems related to traffic flow behavior quickly and easily.

The suggestion that existing languages including those written specifically for simulation such as SIMSCRIPT, SIMPAC, and GPS are adequate to simulate traffic flow does not seem to hold true in actual tests. These languages are well adapted to general purpose simulation but are not structured for dealing with the peculiar problems related to traffic flow. We have experimented with these languages. Although it is possible to program traffic flow simulation models with them, the code generated is extremely inefficient and the ratio of running to real time becomes extremely high. Thus, a successful language to produce simulation programs that will operate on a reasonable ratio of real to simulated time will have to rely on a language of limited generality that is highly efficient for that particular class of simulation problems related to traffic flow.

The comment that the present program has numerous restrictions is true. Although SIMCAR has been referred to as a general purpose traffic flow simulator, in its present form it is restricted to a certain class of problems. It cannot simulate highway networks nor can it simulate multiple-lane highways. Many of these capabilities will be added during the next year to increase its generality. It is unlikely that SIMCAR or any other language utilizing a philosophy similar to that of SIMCAR will have completely generalized capabilities. On the other hand, if the generality can be extended to include most of the commonly encountered highway configuration and network systems, it can be a successful tool for traffic study.